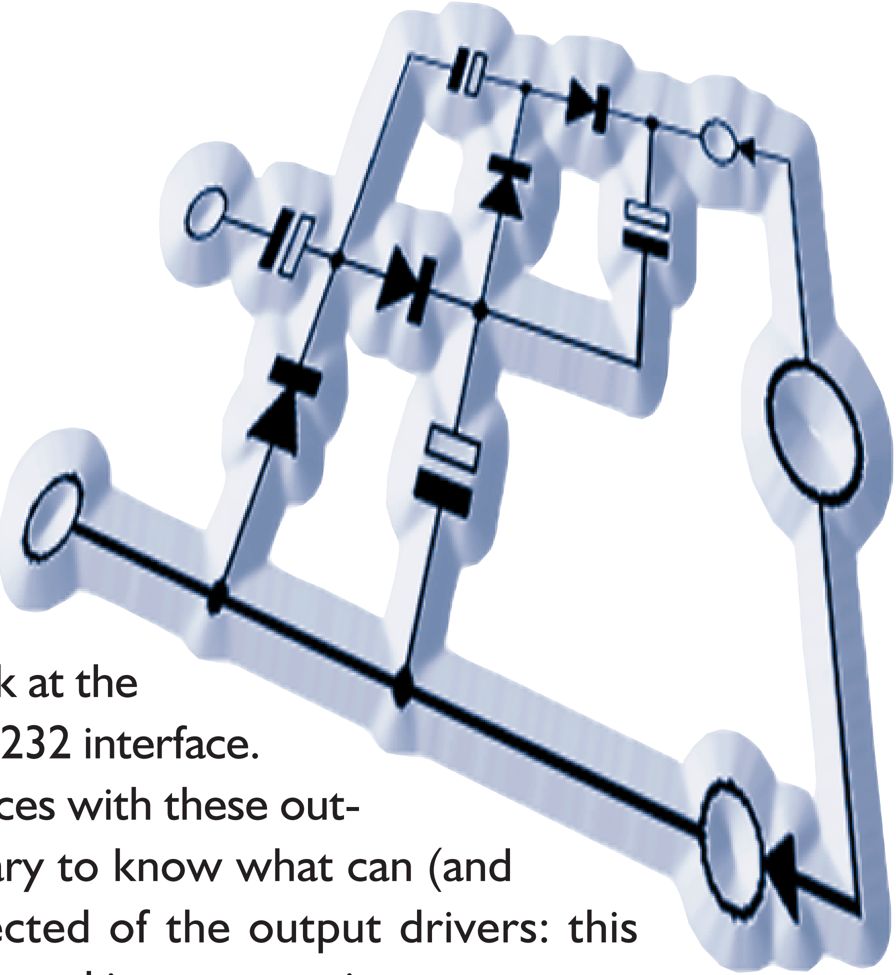
PC Serial Peripheral Design (3)

By B. Kainka



In this third part we look at the output signals of the RS-232 interface. In order to control devices with these output signals, it is necessary to know what can (and what cannot!) be expected of the output drivers: this knowledge can then be used in our experiments.

We have already seen in this course that the output signals of the RS-232 interface swing between –10 V and +10 V. However, because the output current is limited, it is safe to connect an LED directly. But what exactly are the characteristics of the outputs? We shall attempt to answer this question now.

In general, manufacturers of PC equipment follow the RS-232 standard, in which the voltage levels used to send data are specified. It was originally specified that the output voltages should be ±15 V, while at the inputs a signal of at least ±3 V is required. Voltages below –3 V are considered to be a logic '1', and voltages above +3 V are considered logic '0'. Since the outputs deliver ±15 V, and the inputs require only ±3 V, reliable data transfer is assured even over long cables. Noise is much less of a problem than it is with for example the TTL logic levels of 0 V and 5 V.

The standard in theory and practice

Modern PCs no longer adhere to the requirement to generate output voltages of ±15 V. The PC's power supply produces +12 V and –12 V, which are used instead. The ultimate voltage is somewhat lower than this again: this is due to the output drivers used. On separate interface cards the 1488 driver and 1489

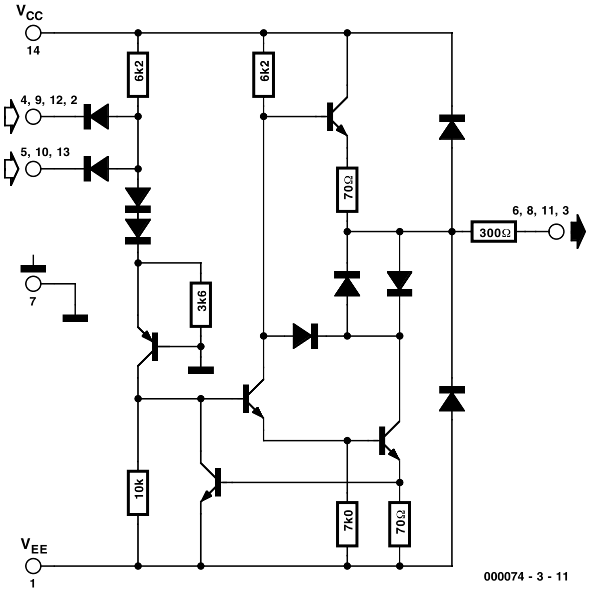


Figure 1. Schematic of the 1488 (source: Motorola)

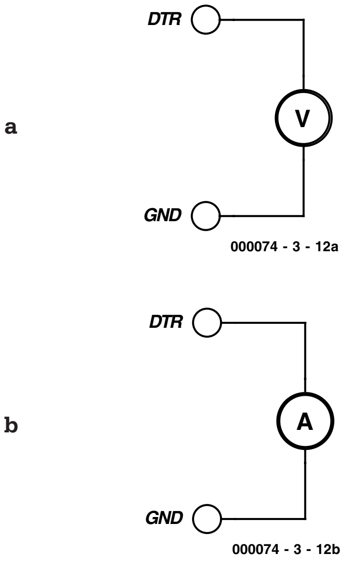


Figure 2. Measuring the open-circuit voltage (2a) and the short-circuit current (2b).

receiver devices are generally used: these have set a *de facto* standard for the behaviour of RS-232 interfaces. **Figure 1** shows the circuit of the driver in the IC. It is clear how the current limiting (set at 10 mA according to the datasheet) is provided. If the output is short-circuited, no more than 10 mA can flow. It can also be seen that 12 V cannot be expected at the output even when a 12 V power supply is used: the voltage drop of the output stage is such that only about 10 V will be produced.

Many PCs are now built with more integrated components, with output drivers already included, which can produce rather different results. It is interesting to determine the exact voltages and currents available from a particular PC. The trend among PC manufacturers is always faster, bigger, better: that means, as far as the RS-232 interface is concerned, higher baud rates over longer cables with greater reliability. To ensure that the higher capacitance of longer cables does not have too great an adverse effect on the pulse shape, the maximum output current must be increased. The outputs of more recent PCs therefore are capable of delivering around 20 mA rather than 10 mA. A total of up to 60 mA can be drawn from the interface. That is handy for our experiments, and is another reason for wanting to make accurate measurements. On some PCs output voltages of ±12 V can indeed be found: these presumably use MOSFETs in their driver output stages.

Table 1

R [kΩ]	I [mA]	U [V]
infinite	0	10.9
22	0.48	10.6
10	1,04	10,4
4.7	2.12	10
2.2	4.18	9.2
1	7.8	7.8
0.47	12.55	5.9
0.33	14.84	4,.9
0.01	25	0.25

Measuring the output characteristics

The output characteristics can be measured very roughly using, for example, a digital multimeter. **Figure 2** shows how to measure the open-circuit voltage and short-circuit current. 'Short-circuit' sounds rather dangerous, but because of its current limiting the RS-232 interface will not be damaged.

The author's PC measures as follows:

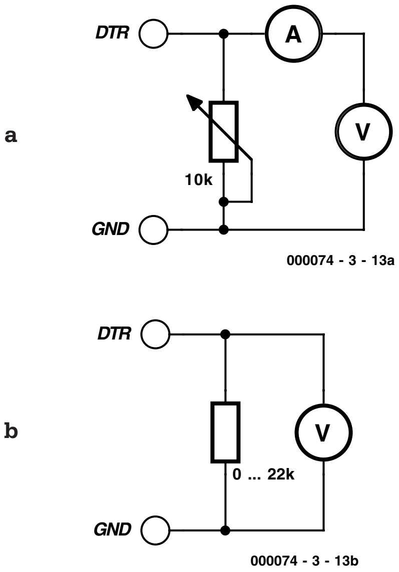


Figure 3. Measurements with variable load.

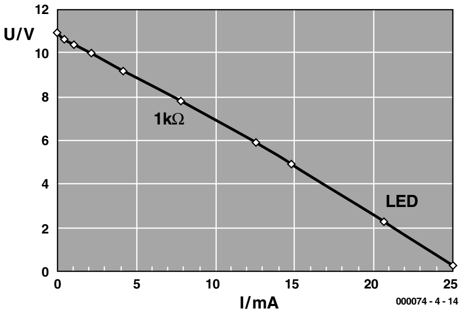


Figure 4. Characteristic curve for one output.

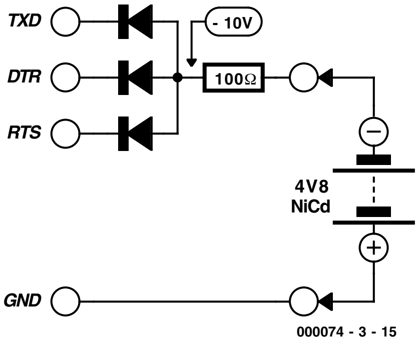


Figure 5. Charging a battery from the RS-232 interface.

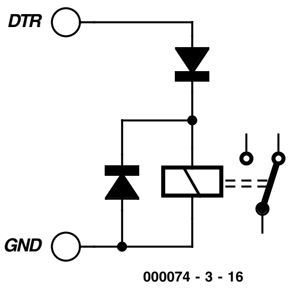


Figure 6. Connecting a relay.

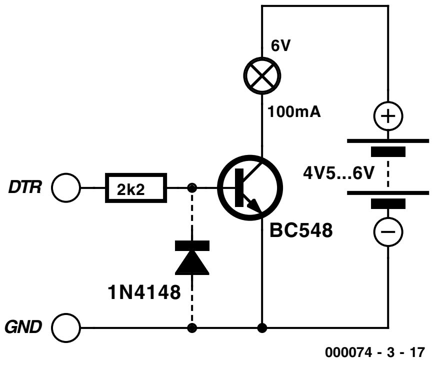


Figure 7. Connecting a transistor switching stage.

Open-circuit voltage: U_0 = –10.9 V (off), U_0=+10.9 V (on)
Short-circuit current: I_{max} = –22.4 mA (off), I_{max}=24.4 mA (on)

A number of measurements must be taken in order to get more exact data for a particular PC: the voltage and current must be measured for a range of loads. A potentiometer (say 10 kΩ) or a set of fixed resistors of various values can be used as a load. If two meters are available, the voltage and current can be measured simultaneously (**Figure 3a**); if only one, the voltage can be measured, and then, as long as the resistor value is known, the current can be calculated (**Figure 3b**). For the example here, we used a set of standard resistors. The voltage was measured and the current calculated using the formula $I=U/R$. The results can be seen in **Table 1**.

Figure 4 shows how the output voltage decreases under increasing load. The lowest-valued resistor, at 10 Ω, gives practically a short-circuit, but a voltage can still be measured. The graph shows, to a first approximation, that the voltage falls linearly with increasing current. The internal resistance of the output can be calculated from the gradient of the graph to be about 430 Ω. A modern bright LED has a forward voltage drop of about 2.2 V. From the graph we can read off the current: about 20 mA. This is about the maximum allowable continuous current for a normal LED. So our measurements show that we can connect an LED without a series resistor.

We used Microsoft Excel to analyse the measurements. If you wish, you can carry out the corresponding experiments for your own PC, which makes a good exercise in measurement and analysis; or you can move straight on to the following experiments.

Uses for the serial interface

If the interface can drive LEDs directly, the current must also be enough for other purposes. As we have already stated, up to approximately 60 mA can be drawn from the interface. We look at a few applications here.

The following practical application is a small battery charger operating from the serial interface. In the circuit shown in **Figure 5** the charging current is about 30 mA. That is adequate for small batteries or for trickle charging. We will work with a negative output voltage: the advantage is that the circuit works immediately the PC is switched on, without having to run a program. If it is desired to use the opposite polarity, the diodes can be reversed and the outputs switched to +10 V in software. You could also control charging automatically in software.

Another example of a device that can be driven directly from the serial interface is a small DC motor. A smooth-running motor, such as the ones found in cassette recorders, can be used, and will run satisfactorily on 30 mA. To obtain this current, several outputs are connected together to drive the motor. With a small modification to the ‘flasher’ program two outputs can be made to switch simultaneously. The motor can then be made to run in either direction.

Small relays can also be connected directly to the interface (**Figure 6**). A diode is normally required to ensure that the relay drops out when the polarity is reversed.

Transistor switching stages

Relays can be used to switch currents greater than that required by LEDs. Cheaper, more elegant and less extravagant is a transistor stage. **Figure 7** shows how a 100 mA bulb can be switched, using an external power supply. The transistor used is a BC548. The principle of the switching stage is very simple: the interface delivers a relatively small base current to the transistor which is amplified, so that the collector current is sufficient to drive the lamp.

How are the components for the switching stage selected? The most important considerations will be discussed briefly here. The operating current of the bulb is 100 mA. This can be provided by a BC548 without difficulty: the maximum collector current allowed is 300 mA. If the lamp current is measured at the moment it is switched on, it will be found that it is considerably greater. When the bulb is cold it has a resistance of about 1/10 of that when it is operating. In theory, then, an instantaneous current of 1 A will flow. In practice, however, the current switched by the transistor is limited.

The bulb filament warms up after only a few milliseconds and so the overload is brief enough to be withstood. If you are not sufficiently reassured by this, you can substitute a BC338 which can withstand a peak current of 800 mA.

The 2.2 kΩ base resistor will have a potential of around 10 V across it. When the output is on, the base current will be about 4.5 mA. The BC548 is available in three gain groups with gains of between 110 and 800. Usually the BC548C is used, with a gain of between 420 and 800. In the pessimistic case a base current of 100 mA/400 = 0.25 mA is required; the actual base current with a 2.2 kΩ base resistor is comfortably more than this. Note, however, that the gain falls at higher collector currents. In any case, the transistor will be driven well into saturation, guaranteeing the smallest possible voltage drop between emitter and collector and keeping power dissipation low both during operation and at the instant the transistor is switched on.

As can be seen, the choice of base resistor is not arrived at by exact calculation, but rather by estimation, since normally the gain of the transistor is not known precisely. It is interesting to try various base resistors to discover over what range reasonable results are obtained. With too high a value, the transistor will not be driven fully into saturation; then the voltage drop becomes greater and the transistor becomes noticeably warm. Also, a resistor which gives satisfactory results in the 'on' state can nevertheless not be able to provide sufficient drive at the instant of turn-on. The lamp appears to turn on slowly, during which time there is considerable power dissipated in the transistor. With too low a base resistor power is wasted in the control circuit, leading also to higher dissipation and possibly to overloading the base-emitter diode by exceeding the maximum allowable base current. The absolute maximum allowable base current is given in the datasheet.

In the circuit diagram a diode is shown connected in reverse between the base and emitter of the transistor. This prevents excessive negative voltages appearing at the base. The maximum reverse voltage of the base-emitter diode generally lies at around –5 V. Breakdown occurs at about –9 V, when a considerable reverse current flows. The transistor behaves like a Zener diode with a voltage of about 9 V. Since in the 'off' state the voltage will be around –10 V, it must be limited. With the diode fitted, the base voltage cannot fall below –0.6 V. It is a worthwhile experiment to investigate the effect of omitting the diode. A reverse current indeed flows, but the transistor nevertheless does not conduct: the lamp remains off. The circuit works even without the diode. It is said that a continuous reverse current over time impairs the noise performance of the transistor; but that will not be a problem here. As so often, it makes a difference whether one is experimenting or designing a circuit in earnest; in the latter case, the diode belongs in the circuit.

AC experiments

The flasher program (Flasher.vbp) produces an alternating voltage on the DTR and RTS outputs, whose frequency can be adjusted up to a limit of about 10 Hz. This lets us try some simple experiments with alternating current. As is well known, a capacitor appears as a resistor to alternating current, conducting the current better at higher frequencies. This can be demonstrated using the circuit of **Figure 8**. Here a capacitor is constructed from two electrolytics connected back-to-back to enable operation with an alternating voltage. This arrangement is sometimes used in driving loudspeakers.

If the flasher program is set to a low frequency, the LEDs alternately flash briefly. At each transition the capacitor is recharged. The current then falls to zero as the voltage across the capacitor approaches the voltage on DTR. If the frequency is increased, the flashes become more frequent and the average brightness of the LEDs also increases. The capacitor presents a lower resistance to the alternating current, and so the (average) current increases.

The alternating voltage produced has a peak value of about 10 V. The peak-to-peak voltage is around 20 V.

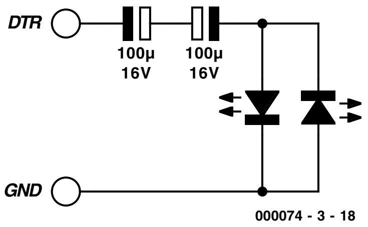


Figure 8. Capacitors as AC resistors.

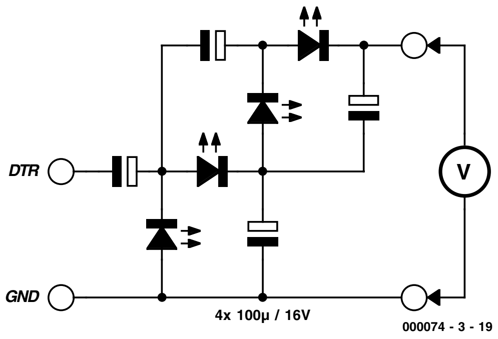


Figure 9. 40 Volts from the serial interface.

Using a special multiplier circuit, a DC voltage of about 20 V can be obtained; using a multiplier cascade a factor of 4 can be achieved, giving about 40 V. The circuit consists of four capacitors and four diodes (**Figure 9**). Here LEDs are used so that the circuit's operation can be seen directly.

When the program is first run, the LEDs flash relatively brightly. The brightness decreases gradually to practically nothing, when the capacitors have charged to their final voltages. A voltage of 40 V can be measured at the output of the circuit. If the capacitors are discharged using a 1 kΩ resistor across the output, the process starts again from the beginning.

This circuit is an example of how LEDs can be 'stressed' by high voltages. This is fine for our experimental purposes, since experience shows that LEDs can cope with the high voltages without difficulty. One should be aware, however, that such circuits hardly represent exemplary engineering practice; for professional applications, silicon diodes (such as the 1N4148) should of course be used.

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